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**AN EVALUATION OF SUPRAMAXIMALLY LOADED ECCENTRIC LEG PRESS
EXERCISE**

AN EVALUATION OF SUPRAMAXIMALLY LOADED ECCENTRIC LEG PRESS EXERCISE

Running title: Mechanical characteristics of eccentric exercise

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ABSTRACT

High intensity eccentric exercise is a potent stimulus for neuromuscular adaptation. A greater understanding of the mechanical stimuli afforded by this exercise will aid the prescription of future eccentric training regimes. This study sought to investigate the mechanical characteristics of supramaximally loaded eccentric exercise when using a custom-built leg press machine. Using a within subject, repeated measures design, 15 strength trained subjects (age 31 ± 7 years; height 180.0 ± 6.8 cm; body mass 81.5 ± 13.9 kg) were assessed under three different conditions; LO, MOD and HI which were equivalent in intensity to 110, 130 and 150%, respectively, of peak force during an isometric leg-press at 90° knee flexion (IMVC). All loading conditions demonstrated a similar pattern of mechanical profile, however, the variables underpinning each profile showed significant ($p < 0.01$) load dependent response (LO vs MOD, MOD vs HI, LO vs HI) for all variables, except for average acceleration. Average force associated with each loading conditions exceeded IMVC, but equated to a lower intensity than what was prescribed. Repetitions under higher relative load intensity stimulated greater average force output, faster descent velocity, greater magnitude of acceleration, shorter TUT and a decline in force output at the end range of motion. This research provides new data regarding the fundamental mechanical characteristics underpinning supramaximally loaded eccentric leg press exercise. The information gathered in the study provides a foundation for practitioners to consider when devising loading strategies, and implementing or evaluating supramaximally loaded eccentric exercise when using a similar exercise and device.

Keywords: maximal force, load prescription, muscle lengthening

INTRODUCTION

Eccentric resistance exercise classically involves resisting an external load during the descending phase of an exercise movement. When performing eccentric resistance exercise using supramaximal external load (>1 RM or isometric peak force) the active muscle will lengthen whilst under high tension; by using this loading regime it means that the force imposed by the load exceeds the opposing force offered by the muscle. In these circumstances muscle force output is in excess of what can be achieved during maximal isometric (19) or concentric (6) exercise, thus can be a means to augment greater muscle tension. Consequently, high intensity eccentric exercise has been shown on numerous occasions to provide a more potent stimulus for neuromuscular adaptation than concentric training (8,11,14).

There is a wealth of evidence to suggest that following habitual use of high intensity eccentric exercise there is an increase in muscle cross-sectional area and morphological alterations of muscle architecture (2), preferential recruitment of type II muscle fibers (13), increase in isometric and concentric force (3,9,10), enhanced task specific gains in eccentric strength (10), reduced neural inhibition and increase in muscle activation (1,17). Because these adaptations are precursors to stronger, larger, faster muscle with the potential to generate more power, there is a great deal of interest in this mode of training from athletes, coaches and practitioners; especially those who operate within strength-power based sports where maximal strength and muscle mass can be important determinants of performance. Unfortunately, the application of high intensity eccentric training in a performance environment is fraught with problems; administering a sufficient stimulus in an efficient manner whilst considering the safety of athletes under extreme loads requires close supervision, assistance, and/or specialist equipment. These limitations have led to

a paucity of information in applied settings (compared to more traditional resistance training methods), thereby limiting the evidence about this activity, and importantly, the potential to understand the application for training prescription and adaptation.

In order to conduct applied investigations of supramaximal eccentric training, coaches and research practitioners must have a safe, achievable and effective protocol. To ensure this, they must first gain an appreciation of the unique mechanical stimulus that will be exerted on the musculoskeletal system, and understand how it may alter with changing conditions. To our knowledge, no study has investigated the mechanical stimulus of supramaximal intensity eccentric exercise using a method that can be replicated in an applied training environment. Therefore, the aim of this research was to investigate three supramaximal intensity eccentric leg press exercise conditions, using a bespoke inclined leg press device. Modification and instrumentation of the inclined leg press device removed the potential limitations associated with high intensity eccentric training practice, such that it was possible to apply very high loads eccentrically and allow an investigation of the fundamental mechanics associated with this mode of exercise. This first step will provide the foundation information that will increase the understanding of the eccentric phase of the leg press exercise and characterize the stimulus afforded by the addition of a supramaximal load. This information will provide practitioners an understanding of the training stimulus provided on similar devices when prescribing, implementing or evaluating high intensity eccentric exercise in their research and practice.

METHODS

Experimental Approach to the Problem

This study used a within-subject, repeated measures design to investigate the mechanical profile of three different supramaximally loaded eccentric exercise conditions; low (LO), moderate (MOD) and high (HI) intensity. Eccentric exercise was performed on an instrumented, custom built leg press machine which defaults as a traditional leg press device, but modifications allow it to be converted to an isometric or eccentric device. Utilizing the machines isometric function, load prescription for each condition was calculated from peak force during an isometric leg-press performed at 90° knee angle (IMVC). A 90° knee angle was chosen for IMVC as it reflected the portion of the leg press movement where force output is most restricted. IMVC was chosen as a prescription method as it was considered time and somewhat energy efficient versus 1RM testing, and has previously been shown to have a strong correlation with 1RM (12). The magnitude of external load applied to LO, MOD and HI conditions were equivalent in intensity to 110, 130 and 150% IMVC, respectively. The range of intensities were chosen to ensure that manipulation in external load (independent variable, IV) was sufficiently different enough to produce mechanical differences in the kinetic and kinematic parameters (dependent variable, DV). A smaller intensity range may have produced similar data across conditions thus making it difficult to draw meaningful conclusions for coaching and research practice. All subjects attended four testing sessions across four consecutive weeks; one session per week, on the same day and at the same time each week to avoid the influence of diurnal fluctuations. Session 1 included IMVC familiarization and following a 10 minutes rest interval, IMVC assessment to attain a baseline for eccentric load prescription. This was followed by eccentric exercise familiarization. Sessions 2, 3 and 4 included the assessment of eccentric repetition characteristics under each loading condition; LO, MOD and HI in a randomized, counterbalanced order.

Subjects

Fifteen males (mean \pm SD; 31 ± 7 years, 180.0 ± 6.8 cm and 81.5 ± 13.9 kg, respectively) volunteered to participate. All subjects were from a strength-power sport background e.g., Olympic weightlifting, rugby, athletics and track sprint cycling, with 11 ± 7 years of resistance training experience, which had included phases of maximum strength training. All subjects were free from musculoskeletal injury for at least 12 months before the study started, and reported no musculoskeletal or cardiovascular disorders. The volunteers were required to avoid unaccustomed exercise during the whole study period, refrain from strenuous exercise in the 48 hours prior to attending each testing and were instructed to attend each session in a well-hydrated and fed state, having abstained from alcohol in the preceding 24 hours. They were advised to keep a consistent routine (nutrition, hydration, general exercise and sleep) in the days prior to attending each testing session, which were completed during the Winter season. Subjects were informed of the benefits and risks associated with the investigation, as well as all study procedures prior to providing written, informed consent. The study procedures and consent documentation was approved by University Ethics Committee in accordance with The Declaration of Helsinki.

Procedures

Equipment and Instrumentation. The custom-built 45° incline leg press machine (Sportesse, Somerset, UK) facilitates performance and assessment of concentric, isometric and eccentric exercise (Figure 1). The machine's default is to act as a traditional leg press device, but modifications allow it to be converted to an isometric or eccentric device. The eccentric function of the leg press operated via a pneumatic system, which enables higher loads (up to 420 kg) to be applied during the eccentric phase of the leg pressing movement. Automatic 'unloading' at the

predetermined end position (descending part of the lift) allowed the user to return the carriage to the start position. The ‘unload’ was achieved with adjustable magnetically operated switches (reed switches) situated on the machines framework. These switches trigger the application and withdrawal of the imposed resistance when the foot carriage passed each switch, thereby reducing the load to allow the user to return the carriage back to the start position under concentric conditions unassisted. The isometric function of the leg press operates via an inbuilt locking mechanism that can secure the carriage at any position along the machines framework. The reliability of the machine to administer eccentric force across 15 different loads between 130 and 420kg, on 2 separate occasions were not significantly difference ($p = 0.11$) and showed strong reliability ($ICC = 1.00$ [95% CI: 1.00, 1.00], $CV = 1.2\%$ [95% CI: 0.9, 2.0]).

The leg press foot carriage comprises of two smaller, independent carriages that connect with a removable steel bar. Mounted onto each carriage were separate force plates. Each force plate consists of two parallel steel plates with 4 s-type load cells (300 kg limit per cell) which were mounted between each plate in each corner. The 4 load cells fed into a combinator to create a single voltage output. Associated with each force plate was a potentiometer (Hybritron®, 3541H-1-102-L, Bourns, Mexico). The load cells and potentiometers sampled at 200 Hz. The voltage from the load cells and potentiometers were relayed into data acquisition software (LabVIEW 6.1 with NI-DAQ 6.9.2, National Instruments Corporation, USA) on a desktop PC. Force-time trace for each force plate (left and right) and displacement- and velocity-time trace for each potentiometer (left and right) were displayed. Raw data was exported from the data acquisition software into Microsoft Excel format (Microsoft Excel, 2010) and were analyzed offline.

INSERT FIGURE 1 ABOUT HERE

Warm-up. Prior to testing, a standardized warm-up was completed using a cycle ergometer (Wattbike Pro, Wattbike Ltd., Nottingham, UK) pedaling at 70 - 80 revolutions·min⁻¹ between 110 - 120 W for five minutes. Immediately following this, five minutes of dynamic mobility exercises were completed that targeted the trunk, hips and lower limbs. This was followed by 8, 6 and 4 repetitions of the leg press at an external intensity equivalent to 70, 85 and 100% of body mass, respectively. Each set was separated by 2 minutes.

IMVC Familiarization and Testing. Following the warm-up, subjects were familiarized with the IMVC test protocol. Securing the leg press carriage at 90° of the subjects' knee flexion (verified by goniometry), they completed 3 x 1 repetition at each of the following perceived intensities; 50%, 75% and 100% for 3 seconds per repetition. Between each repetition subjects were given 30 seconds recovery, and 2 minutes recovery between each intensity. Following this, subjects rested for 10 minutes before formally assessing IMVC. This assessment consisted of 3 maximum efforts of 5 seconds, interspersed by 3 minutes rest. Subjects were advised to 'gradually build up force to reach maximal capacity, until instructed to stop'. Instructions were standardized and all subjects received the same verbal encouragement during each effort. IMVC data were collected using the machines force plate system. The trial showing highest IMVC was taken for analysis and used for eccentric load prescription. Pilot tests showed two repeated sessions, separated by 7 days were not significantly difference ($p = 0.48$), and showed strong reliability (ICC = 0.99 [95% CI: 0.95, 1.00], CV = 4.65% [95% CI: 3.15, 6.14]).

Eccentric Familiarization and Testing. Familiarization during session 1 included 3 x 3 repetitions with an external load equivalent to 75% and 85% IMVC, and 3 x 1 repetitions with an external load equivalent to 100% IMVC. All sets were separated by 3 minutes recovery. During session 2, 3 and 4, prior to testing eccentric performance under supramaximal load, subjects completed a warm up and an eccentric preparation task. This were to ensure incremental preparation to become accustomed to the heavier loads, and thus reducing the potential for injury. Preparation included; 3 repetitions and 2 repetitions with an external load equivalent to 75% and 100% IMVC, respectively. Preceding the LO trial an additional 1 repetition with an external load equivalent to 100% IMVC was completed, preceding the MOD trial an additional 1 repetition with an external load equivalent to 110% IMVC was completed, and preceding the HI trial an additional 1 repetition with an external load equivalent to 130% IMVC was completed. All repetitions were 3 seconds eccentric time under tension (TUT). Each session, testing comprised of 4 x 1 repetitions at either LO, MOD or HI intensity, separated by 5 minutes to minimize the effects of fatigue. Each session was randomly assigned either LO, MOD or HI intensity. The same verbal encouragement was provided throughout each testing session.

The performance requirements of the eccentric exercise were to; 1) halt the supplementary load before initiating any lowering action; 2) initiate the lowering action as slowly and as controlled as possible and continue this action over the whole ROM; 3) resist the carriage from accelerating downwards throughout the whole ROM; 4) react as fast as possible as the eccentric load is withdrawn to push the carriage upwards. This last instruction was to promote continued force production throughout the whole ROM and to prevent the subjects from dropping the carriage to the safety stops. During this movement the following variables were of interest; average force

(N), end force (N), TUT (s), average velocity ($\text{m}\cdot\text{s}^{-1}$), and average acceleration ($\text{m}\cdot\text{s}^{-2}$). These data were captured between the start of the repetition (maximum displacement of the foot carriage = 10° knee flexion) and the end of the repetition (zero displacement of the foot carriage = 90° knee flexion). These were the locations that corresponded with the application and removal of the added eccentric load. For each condition, the trial that most satisfied the performance requirements were taken for analysis. Force data for the left and right side were summed to reflect the bilateral nature of the exercise.

Statistical Analyses

Intraclass correlation coefficients (ICC) and coefficients of variation (CV, %) including 95% confidence intervals were calculated to determine the repeatability of eccentric performances between 2 repetitions (7). Using SPSS (Version 24.0; SPSS Inc, Chicago, USA) a repeated measures ANOVA was used to determine significant differences in the DV's; force (average and end), TUT, velocity and acceleration between each loading condition (IV) and where appropriate, a Bonferroni *post-hoc* test. Group data are presented as mean \pm SD with 95% confidence intervals (CI). Data are supported with effect sizes (partial η^2); α was set at $p \leq 0.05$, *a-priori*.

RESULTS

The ICCs revealed a high within session reliability for average force; LO ($p = 0.17$, ICC = 1.00 [95% CI: 1.00, 1.00], CV = 0.92% [95% CI: 0.63, 1.22]), MOD ($p = 0.41$, ICC = 1.00 [1.00, 1.00], CV = 0.83% [0.56, 1.10]), HI ($p = 0.98$, ICC = 1.00 [1.00, 1.00], CV = 0.52% [0.35, 0.68]). Reliability for TUT was acceptable; LO ($p = 0.69$, ICC = 0.96 [0.90, 0.99], CV = 7.54% [5.12, 9.96]), MOD ($p = 0.53$, ICC = 0.95 [0.86, 0.98], CV = 8.61% [5.85, 11.38]), HI ($p = 0.65$, ICC =

0.98 [0.94, 0.99], CV = 5.99% [4.06, 7.91]). The results show that IMVC peak force equated to 2794.4 ± 811.9 N (95% CI: 2325.7, 3263.1). Average force associated with each loading conditions exceeded IMVC peak force but was less than the prescribed external force. This meant that the *actual* intensity of each loading condition was equivalent in intensity to $101.0 \pm 4.0\%$ (95% CI: 98.3, 102.8), $116.0 \pm 4.0\%$ (95% CI: 113.8, 118.2) and $132.3 \pm 8.1\%$ (95% CI: 127.8, 136.7) for LO, MOD and HI, respectively. All loading conditions demonstrated a similar pattern of mechanical profile (Figure 2), however, the variables underpinning each profile showed significant ($p < 0.01$) load dependent response (LO vs MOD, MOD vs HI, LO vs HI) for all variables, except for average acceleration which was significantly different between LO and HI, only ($p = 0.05$) (Table 1). Force at the end ROM was 1%, 3% and 5% less than the average force measured over the ROM for LO, MOD and HI trials respectively.

INSERT FIGURE 2 ABOUT HERE

INSERT TABLE 1 ABOUT HERE

DISCUSSION

The aim of this research was to investigate the fundamental mechanical characteristics associated with supramaximal intensity eccentric leg press exercise. The results showed that the heavier relative external load stimulated greater average force output which, in turn, was associated with a faster descent velocity and shorter TUT. With each increment in external load (LO vs MOD, MOD vs HI) average force output increased $\sim 12\%$ and average descent velocity increased by $\sim 35\%$, which was equivalent to a decrease in TUT of $\sim 26\%$. The eccentric force output under each loading condition was less than the force imposed by the external load. Because of this, the

intensity of the supramaximal load was less than the prescribed 110, 130 and 150% relative to peak force exerted during the IMVC. Each condition displayed a similar mechanical profile throughout the ROM; but with the heavier external load, a decrease in force output, and concomitant increase in velocity and acceleration was prominent towards the end ROM (Figure 2).

In this study, supramaximal eccentric-only exercise was employed to explore the strength potential of eccentric actions without the limitation of concentric force capacity. The eccentric protocol was focused on reducing net forces to decelerate the foot carriage and descend in a slow and controlled movement. This eccentric-only movement has minimal involvement of the stretch-shortening cycle (SSC) (5), and the slow nature of this exercise perhaps lacks task-specificity to some sports (18). However, the extended TUT at high levels of force exceeds what can be achieved with traditional resistance exercise. =Consequently this could provide a potentially powerful stimulus for musculoskeletal adaptation and thereby be of use for long-term athlete development to increase muscle strength and size, given that the mechanical stimuli is integral to induce adaptation (10). To understand the acute and chronic responses to this type of eccentric exercise and the different force-TUT interactions more research is warranted, particularly given the growing interest in elite sport to maximize adaptation from eccentric loading.

The force-time traces showed that the eccentric protocol induced a relatively stable force output across the majority of the working range (Figure 2A). Because of this feature, average force was used to quantify the relative intensity of each eccentric effort. On this basis, the intensity of each loading condition equated to ~101, ~116 and ~132% of peak force exerted during IMVC. The

disparity in prescribed versus actual load is attributed to the voluntary reduction in force output to assist the carriage to descend. In all conditions force of the external load and muscle force are not equal; the slower the intended velocity of the descent, the closer the force expressed by the subject is to equaling the force imposed by the load (16). Therefore, in the absence of instrumentation, when training with slower velocities, the external load would provide a good representation of the intensity of the force being exerted. The opposite is true for repetitions with faster descent velocity, whereby faster velocities will be more distant from the prescribed load.

Under these intensities, the higher loading conditions tended to show a force decline towards the end ROM (Figure 2A). This indicates that the force of the applied external load became too great to resist at the same target velocity. This resulted in some acceleration towards the end of the ROM. It is important to be mindful of these changes in acceleration at higher intensities if the intention of the training stimulus is to provide an even and stable stimulus throughout the working range. Previously, practitioners and researchers have used a 3% decline in force as a cut-off criterion to ensure the provision of a stable stimulus (15). When applying this criterion to these data, the LO trial showed a decline in force output of 1%, MOD declined by 3% and the HI declined by 5%. Based on the above criterion, the efforts under the HI loading condition might not be acceptable. Nonetheless, the force output in the HI condition generated a great deal of muscle tension, so if the aim is to load an athlete with similar loads, practitioners should be mindful that the load is not well tolerated in more flexed positions and could have implications for safe execution of the movement.

The prescription of eccentric load intensity for each condition used angle-specific isometric assessment. Individuals tended to show slightly different responses to the same relative load when prescribing relative to isometric strength. This could be expected given that neural control strategies during eccentric and isometric actions are different (4). As such, it seems apt to suggest that future research should establish task-specific methods of eccentric assessment. This would enable practitioners to accurately determine an individual's eccentric force producing capacity and prescribe eccentric training more accurately. Notwithstanding, using the isometric method as a basis for load prescription enabled successful implementation of three different supramaximal eccentric exercise protocols.

The custom-built instrumented leg press reduced common methodological issues regarding the ability to perform high intensity eccentric exercise efficiently and safely. The outcomes have facilitated the evaluation of the fundamental mechanical characteristics underpinning eccentric exercise during the leg press movement, and has highlighted how changes in external load conditions can influence these characteristics. This has increased our understanding of the eccentric phase and mechanical stimuli afforded by such high intensity actions.

PRACTICAL APPLICATIONS

Overall, supramaximally loaded eccentric-only exercise appears to offer a unique and potent stimulus; individuals can be exposed to extended TUT at high levels of force that exceed what more traditional regimes might offer. When implementing supramaximal loaded eccentric-only repetitions, practitioners should be mindful to prescribe a load that is well tolerated in the restricted

portion (end ROM) of the exercise movement to facilitate continued force production and maintenance of muscular tension for sustained and consistent movement. This study has addressed the acute mechanical response to supramaximally loaded eccentric-only exercise under different magnitudes of external load. As the experimental approach was devised with practical application in mind, the results provide strength coaches and applied practitioners with a greater understanding of the mechanical demand imposed by supramaximally loaded eccentric-only leg press exercise. Importantly, these data provide new insight into the performance response from strength-trained individuals throughout supramaximal eccentric leg press exercise.

Conflict of interest statement

The authors declare no conflict of interest

Author contributions

Experiment planning and design: MH, DF, MR, GH. Data collection: MH. Data Analysis: MH, GH. Interpreted results of research: MH, GH, AW, KH. Manuscript preparation: MH, GH, AW, KH.

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Figure Legends

Table 1. Mechanical characteristics of eccentric leg press repetitions during LO, MOD and HI intensity loading conditions

Figure 1. The leg press device. *Left photo*: Incline leg press with; (A) unilateral force plates, (B) air compression unit, (C) removable steel bar insert, (D) safety pins, (E) adjustable seat. *Right photo*: Underneath the foot carriage; (F) adjustable ROM sensors.

Figure 2. A representative mechanical profile for a single eccentric leg press repetition under three supramaximal loading conditions. Black solid line: LO intensity loading condition, dark grey solid line: MOD intensity loading condition, light grey solid line: HI intensity loading condition, dashed black line: IMVC at 90° knee flexion. A: force-time profile, B: displacement-time profile, C: velocity-time profile, D: acceleration-time profile.

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TABLE 1. Mechanical characteristics of eccentric leg press repetitions during LO, MOD and HI intensity loading conditions

Variable	LO						MOD						HI						ANOVA
	95% CI						95% CI						95% CI						Significance
	Mean	±	SD	Lower	Upper		Mean	±	SD	Lower	Upper		Mean	±	SD	Lower	Upper		<i>p</i>
Prescribed Force (N)	3073.8	±	893.1	2579.2	3568.4	<i>b,c</i>	3632.7	±	1055.5	3048.2	4217.2	<i>a,c</i>	4191.6	±	1217.9	3517.1	4866.0	<i>a,b</i>	< 0.01
Av. Force (N)	2812.6	±	832.8	2351.5	3273.8	<i>b,c</i>	3240.1	±	872.9	2756.6	3723.5	<i>a,c</i>	3626.1	±	857.5	3151.2	4101.0	<i>a,b</i>	< 0.01
End Force (N)	2795.4	±	810.7	2346.4	3244.3	<i>b,c</i>	3148.3	±	850.3	2677.4	3619.2	<i>a,c</i>	3446.5	±	799.4	3003.8	3889.2	<i>a,b</i>	< 0.01
TUT (s)	8.1	±	2.2	6.9	9.3	<i>b,c</i>	6.0	±	1.5	5.2	6.8	<i>a,c</i>	4.4	±	1.0	3.9	5.0	<i>a,b</i>	< 0.01
Av. Velocity (m·s ⁻¹)	-0.03	±	0.01	-0.03	-0.04	<i>b,c</i>	-0.04	±	0.01	-0.03	-0.05	<i>a,c</i>	-0.06	±	0.02	-0.05	-0.07	<i>a,b</i>	< 0.01
Av. Acceleration (m·s ⁻²)	-0.002	±	0.002	-0.003	0.000	<i>c*</i>	-0.003	±	0.004	-0.005	0.000		-0.008	±	0.010	-0.013	-0.002	<i>a*</i>	= 0.05

a = sig diff from LO, *b* = sig diff from MOD, *c* = sig diff from HI at alpha level $p < 0.01$ ($*p < 0.05$), calculated using Bonferroni *post-hoc* analysis.

Figure 1.

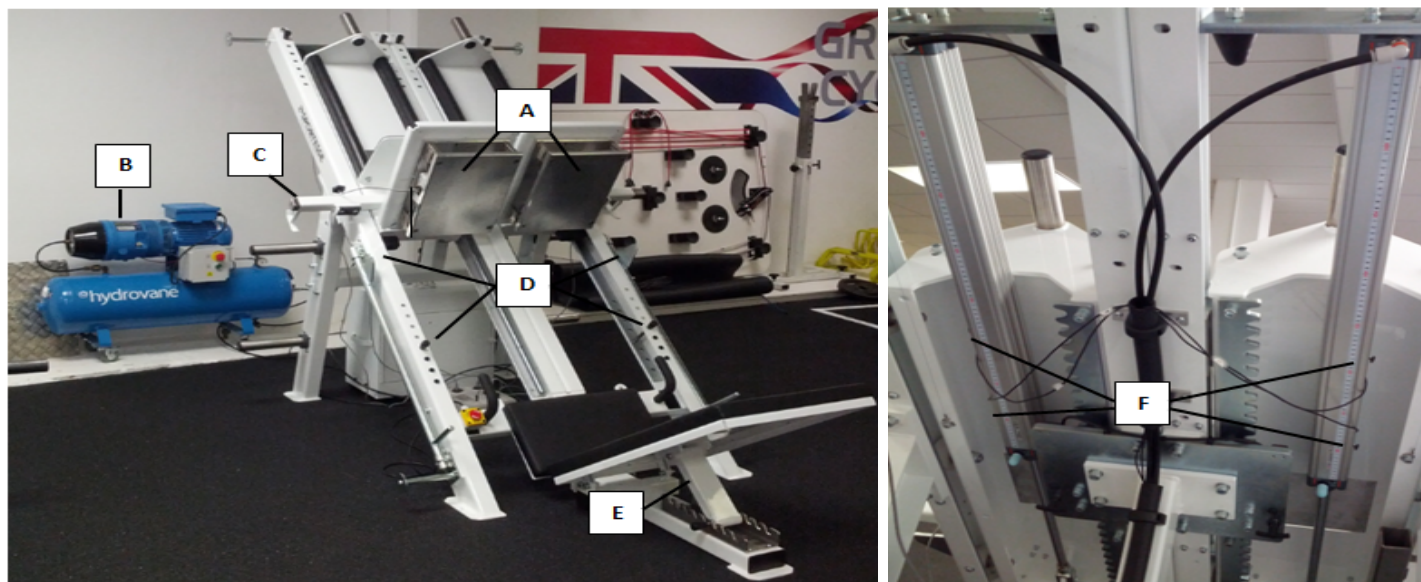


Figure 2.

